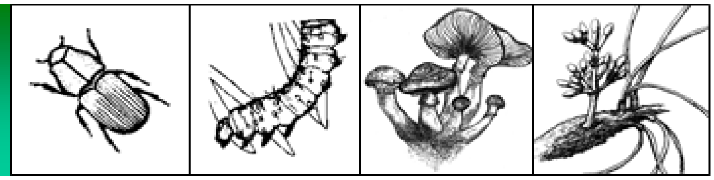
Forest Health Protection



20-01 **OCTOBER 2020**

Western hemlock looper-caused defoliation on the Nez Perce-Clearwater and Idaho Panhandle National Forests

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Abstract

The western hemlock looper, *Lambdina fiscellaria lugubrosa* (Lepidopetra, Geometridae) (Hulst), is a destructive native defoliator of most conifers and some broadleaved species (Alfaro et al. 1999). In 2019, aerial detection surveyors mapped approximately 425,000 acres of hemlock looper defoliation across the Northern Region (all land ownerships). Currently, western hemlock looper-caused defoliation is being monitored on 12 plots located on the Nez Perce-Clearwater and Idaho Panhandle National Forests, Idaho. Plot composition included tree (≥5-inch dbh) densities from 95 to 280 ft^2/acre. Sapling size class densities (1 - 4.9-inch dbh) varied from 100 to 1800 trees/acre. Data indicate that overstory western red cedar, *Thuja plicata* Donn ex D. Don and subalpine fir, *Abies lasiocarpa* (Hook.) Nutt. endured the highest levels of defoliation in 2019, followed by grand fir, *Abies grandis* (Dougl. ex D. Don) Lindl., Douglas-fir, *Pseudotsuga menziesii* (Schwerin) Franco and Engelmann spruce, *Picea engelmannii* (Parry). The highest proportion of overstory tree defoliation was observed in the 5-9.9-inch diameter class. This report summarizes the 2019 collaborative efforts, observations, insect collections, and installation monitoring data collected across the range of the hemlock looper outbreak in northern Idaho. We have included additional 2019 information from the hemlock looper rearing project being completed by University of Idaho. As well, we discuss 2020 observations of live insect collections.

Background

Western hemlock looper is an important disturbance agent of North American forests. In British Columbia, tree mortality can occur rapidly, within two years of the start of infestation. The most severe infestations have occurred in coastal and interior wet belt regions, largely in mature hemlock and hemlock-cedar stands (Alfaro et al. 1999). During outbreaks, western hemlock looper has been reported feeding on several other host tree species and some broad-leaved forest trees and shrubs (Jardine 1969 and Alfaro et al. 1999). Hemlock looper outbreaks may span one to five years and usually begin to collapse around year three due to natural predators, parasites, diseases, virus and sometimes weather.

United States Department of Agriculture	Forest Service	Northern Region	Region One 26 Fort Missoula Rd Missoula, MT 59804-7203	

Western hemlock looper occurs from Oregon north through British Columbia (56^{o} N latitude south) and up into southeast Alaska. A related species, hemlock looper (*Lambdina fiscellaria, Lambdina fiscellaria fiscellaria*) occurs in eastern North America from Georgia north to Nova Scotia and west. Sperling et al. (1999) reported the three subspecies (eastern hemlock looper *L.f. fiscellaria*, western hemlock looper *L.f. lugubrosa*, and oak looper *L.f. somniaria*) as a single species with genetic polymorphism, based on mitochondrial DNA sequencing. However, global databases, local experts, pheromone studies (Gries et al. 1993), and recent publications list these insects as three distinct subspecies. Due to DNA sequencing results and single species suggestions, we have included information on both hemlock looper (*L.f.*) and western hemlock looper (*L.f.l.*) in this report.

Figure 1. Aerial views of western hemlock looper defoliation on the Nez Perce-Clearwater NF in August 2019 (Photo credit: Scott Sontag).

2019 Aerial Survey Observations

In August 2019, western hemlock looper defoliation was mapped by aerial surveyors in Montana and Idaho (Figure 1). The late August 2019 aerial surveys were appropriately timed to capture the complete signature from hemlock looper feeding. Approximately 425,000 acres of hemlock looper defoliation was mapped across Region 1, with the majority in Idaho and approximately 5% in Montana. Defoliation in 2018 was recorded as western spruce budworm in the same counties where western hemlock looper defoliation was recorded in 2019. It is likely that the 2018 western spruce budworm acres recorded for these counties were the result of western hemlock looper defoliation. The majority of 2019 aerially recorded defoliation occurred in Clearwater, Idaho and Shoshone counties in northern Idaho and Lincoln county, Montana. The North Fork Ranger District, Nez Perce-Clearwater National Forests experienced the highest number of National Forest System (NFS) acres impacted from hemlock looper in 2019 (140,076 acres). Surveyors mapped most of the Idaho Panhandle National Forests hemlock looper damage on the St. Joe Ranger District (79,000 acres).

Warmer and drier growing season conditions correlate with western hemlock looper population growth. McCloskey et al. (2009) reported periods of soil moisture deficits during the month of June were associated with the onset of western hemlock looper outbreaks, as were warmer and drier conditions during the growing season two years prior to the first year of visible defoliation. In northern Idaho, moderate and severe drought was recorded for multiple growing months in 2017, 2018 and 2019 (Table 1).

Table 1. Relative drought during summer months across the Nez Perce – Clearwater NF based on NOAA, Palmer Z-Index (Aug 26, 2019).

	Year		
	2017	**2018**	**2019**
June	mid-range moisture	mid-range moisture	moderate drought
July	moderate drought	moderate drought	mid-range moisture
Aug	severe drought	moderate drought	
Sept	Moderate moisture	severe drought	

Outbreak history

In western Montana and northern Idaho, western hemlock looper outbreaks have been recorded in 1937-1939, 1971-1973, 1990-92, 2000-2003, and 2010-2011. In the 1937-1939 outbreak, the greatest damage was on the St. Joe, Coeur d'Alene and Clearwater National Forests (Evenden 1944). Evenden reported losses of up to 60% of stems in the severely defoliated category. In the 1970's, western hemlock looper infestations increased on the St. Joe and Clearwater National Forests (personal communication, Ciesla 2020). In 1971, Region 1 entomologists reported that over 10,000 acres of visible defoliation on grand fir was detected on forests in central Idaho (Dewey et al. 1972). In 2010, defoliation from a western hemlock looper outbreak on the Nez Perce-Clearwater NF was confirmed by Pederson during a certification stand assessment on the North Fork Ranger District. Further observations in the French Mountain-Hemlock Butte Ridge vicinity found high adult moth populations, typical hemlock looper feeding patterns, and heavily defoliated subalpine fir (Pederson 2010). Aerial detection survey (ADS) mapped hemlock looper defoliation as western spruce budworm in both 2010 and 2011 across areas of the Nez Perce-Clearwater NF.

Western hemlock looper adults were noted across the Nez Perce-Clearwater NF in 2009, while deploying Douglas-fir tussock moth traps. At that time, defoliation was neither detected on the ground nor by ADS. By 2010, looper-caused defoliation was becoming apparent across those same areas, although western hemlock looper was not recorded as a defoliating causal agent during ADS. Instead 9,700 acres of "unidentified defoliator" polygons and 62,500 acres were recorded as larch needle cast. Ground-truthed portions of polygons recorded as unidentified or needle cast revealed western hemlock looper to be in the mix, especially in unidentified defoliator polygons. Subalpine fir was predominantly impacted, with moderate to heavy defoliation occurring in all size classes. Moderate to minor amounts of defoliation were found on western hemlock, western larch, grand fir, Engelmann spruce, and western white pine. In addition to these findings, accounts of western hemlock looper larvae, or "inchworms", were being reported in considerable numbers in those areas by field-going, North Fork Ranger District, Nez Perce-Clearwater NF personnel.

In 2011, ADS reported approximately 79,000 acres of defoliation on the Clearwater National Forest from larch needle cast, western hemlock looper (16,000 acres), western spruce budworm (42,000 acres) and an "unknown defoliator". Much of this activity was recorded across the Weitis Creek drainage system, North Fork Ranger District. Several of the defoliated polygons, particularly ones labeled western spruce budworm, were ground-truthed, only to reveal high numbers of western hemlock looper larvae preferentially attacking subalpine fir. All age classes were either partially or completely defoliated. Western hemlock, grand fir, western larch, Engelmann spruce, and western white pine, were lightly or moderately defoliated, like observations in 2010. Ground verification also confirmed that multiple drainages in northern portions of the Moose Creek Ranger District, Nez Perce National Forest had heavy western hemlock looper defoliation.

It is likely that defoliation coded as western spruce budworm, needle disease, and unknown defoliator in 2010 and 2011 was caused by western hemlock looper. We offer two explanations for this interpretation. First, western spruce budworm is not known to have explosive, single year outbreak events. Outbreaks typically last several years and may persist up to 25 years or more. This life history characteristic lends to the likely misidentification of defoliation attributed to western spruce budworm in northern Idaho recorded in 2010 and 2011 was caused by western hemlock looper. Second, the inherent difficulties associated with aerial survey detection affect survey accuracy even for the most experienced surveyors. As well, capturing insect signatures requires biologically appropriate timing of flights. Mapping accurate insect defoliation intensity has added difficulty. Forest, landscape or stand level defoliation from the vantage point of aircraft often appears more severe than actual defoliation on trees in the affected forest. Only the tops and sides of the outer crowns are visible, so that defoliation of new growth can look dramatic even though all or most older needles are intact. Aerial observers must identify host, pest, and extent of damage intensity to the best of their ability within seconds of viewing from a single engine aircraft moving approximately 100 miles/hour. Commonly, it is most difficult to record low levels of insect defoliation from the air. This often results in limited defoliation data for the first year of an outbreak, when needle feeding is at low or light defoliation levels.

Insect biology and life history

Western hemlock looper is a native defoliating insect of North America. Hosts include western hemlock *Tsuga heterophylla* (Raf.) Sarg., true firs *Abies* spp., and Douglas-fir. During the most recent 2019 northern Idaho outbreak, entomologists observed insects feeding on Engelmann spruce, western red cedar, mountain hemlock *Tsuga mertensiana* (Bong.) Carrière, Pacific yew *Taxus brevifolia* (Nutt.), western white pine *Pinus monticola* (Douglas ex D. Don), huckleberry *Vaccinium membranaceum*, and lodgepole pine *Pinus contorta* (Douglas ex Loudon) in addition to grand fir, subalpine fir, and Douglas-fir hosts. The most severe damage occurs in stands of old-growth trees (Anon. 1968). Defoliation often occurs for three years before the outbreak is controlled by natural agents (Dewey et al. 1972).

Hemlock looper larvae hatch from eggs in late spring and early instars begin feeding on newly opened buds in the upper crown of host trees (Figure 2). As larvae grow larger, from June to September, they feed on both new and old foliage. Young larvae may feed on understory vegetation of various tree or shrub species. The larvae are wasteful feeders, chewing off needles at their bases and causing the tree crowns to appear yellowish-red and then brown in color. In heavy infestations, trees may be stripped in a single season. Typically, between September and November, larvae move to bark crevices, moss, lichen or under debris to pupate. Adult moths emerge 10-14 days later, and females lay eggs on bark, or associated moss and lichens or even downed logs (Rochefort et al. 2011, personal communication). Adults are active from mid-August to November, and winter is spent in the egg stage (Figure 2).

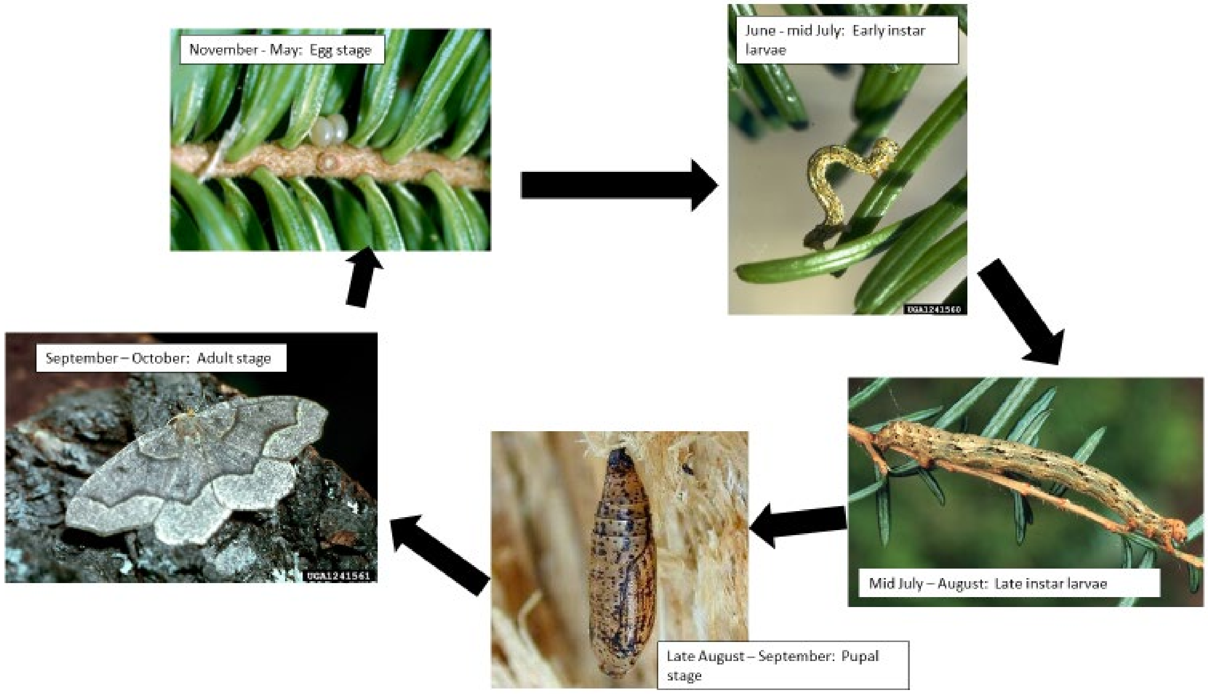

Figure 2. Western hemlock looper insect life cycle (Photo credits: egg stage Valent Biosciences; early instar larva and adult stage / moth Jerald Dewey, USFS, Bugwood.org; late instar larva Canada Natural Resources; pupa Moth Photographers Group).

Hemlock looper populations are usually regulated by natural controls. As with most host-prey systems, there is a lag of one or more years for the prey (or other natural control agents) to respond to the increased host availability. Biotic controls include predators (insects and birds), egg and pupal parasitoids, and viral and fungal diseases (Randall 2010). Internal and external symptoms of polyhedrosis virus in western hemlock looper larvae are generally similar to nuclear polyhedrosis virus (NPV) in other Lepidoptera (Sager 1957). High levels of parasitism by *Telenomus* spp. have been reported for many forest defoliating Lepidopetra (Anderson 1976, Anderson and Kaya 1977, Drooz et al. 1977, Torgersen and Mason 1985). Egg parasitoids of the genus *Telenomus* (Haliday) (Hymenoptera: Scelionidae) can be highly efficient natural control agents of insect pests (Legault et al. 2012). Parasitism levels above 50% reported early in the season suggest that *Telenomus* spp. females are active at low temperatures (Hebert et al. 2006). Large numbers of *Phyrnalydella* sp. (Diptera) and *Itoplectis montana* Cush. (Hymenoptera) were reported during the 1937-9 northern Idaho western hemlock looper outbreak (Evenden 1938). Variability in hemlock looper egg parasitoids occurs throughout the season: *Trichogramma* spp in the fall, *T. droozi* in the spring, *T. coloradensis* in both fall and spring. *Trichogramma coloradensis* and *T. droozi* have the ability to successfully parasitize eggs at very low temperatures (4 - 8^{o}C). Mean parasitism rates increased by late spring and early summer with mean annual air temperature increases (Legault et al. 2012). Eight species of Ichneumonidae pupal parasites were identified by Torgersen, causing anywhere from 2-27% looper parasitization (1971).

Abiotic indirect controls, such as abnormal weather events, have the capacity to reduce western hemlock looper success. For example, extensive rain events during the adult stage can limit adult moths' ability to successfully lay eggs (Randall 2010). In addition, severe winter temperatures outside of the normal season window (earlier in the fall or in the early summer) can weaken hemlock looper success. In late September 2019, there was a winter storm that developed and dropped approximately three inches of snow in the higher elevations of northern Idaho. This winter precipitation event occurred while western hemlock looper adults were the primary life stage. At the time of our October surveys, we noted dead moths laying on the ground as well live adults still flying.

In North America, most insects exposed to sub-zero temperatures are freeze avoidant (Leather et al. 1993, Denlinger and Lee 2010). They also produce and accumulate glycerol, which acts as an antifreeze protecting their bodies from ice forming damage. Hemlock looper eggs have a mean supercooling point lower than -30^{o}C from October through the following spring; the lowest values observed were -47^{o}C in February (Rochefort et al. 2011). For phytophagous insects, such as hemlock looper, the amount of energy reserves stored depends on the availability and the quality of their host plant (Hough and Pimentel 1978, Rossiter 1991, Roder et al 2008). Studies have shown a significant impact of parental larvae feeding material, host tree species as well as location, in the supercooling capacity of populations of hemlock looper eggs (Rochefort et al. 2011).

Methods

Western hemlock looper collection, 2019: August 25 and 26th 2019, entomologists collected hemlock looper at several locations on the Nez Perce-Clearwater NF, along Forest Service Roads 471, 1199, 471, 464, 1875, and 9824A. These surveys were brief and aimed at making collections along the road from all hosts with looper-caused defoliation symptoms. Entomologists did not focus on making clean collections or consider the role of cross-contamination of viral or fungal controls between collection points. The same beat sheet was used for all collections. Insects from each collection point were maintained in separate cups and vials. The larvae and pupae collected during these surveys were later processed in the Coeur d'Alene Forest Health Protection laboratory. Collections were maintained at 3^{o}C in paper cups with adequate host tree foliage for feeding for up to 10 days. Larvae were examined for symptoms associated with virus and entomophagous fungi (Sager 1957). Pupae were examined for parasitoid presence. After processing, live larvae and pupae were maintained to ensure they were healthy and tallied as healthy adults (free of parasitoids, fungal infections and virus) upon finding adult moths emerged.

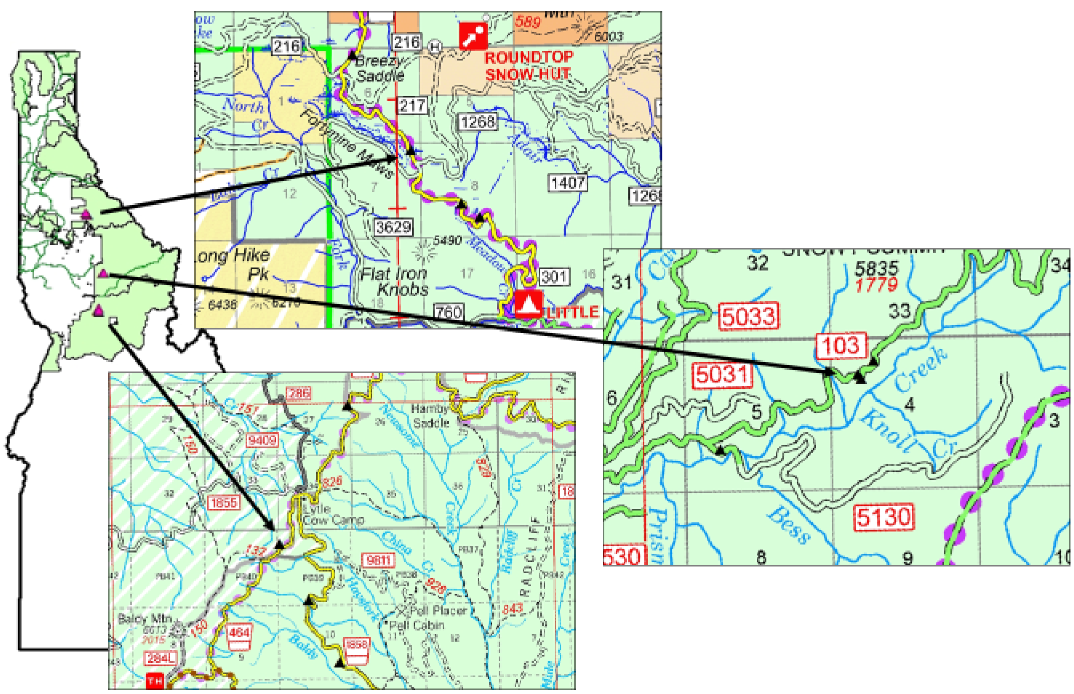

Figure 3. Four plots were established at three study sites (Avery, Clearwater, and Nez Perce). Study sites are depicted by pink triangles (left). From north to south, four plots were installed at St. Joe, Clearwater, and Nez Perce. Plot locations are represented by black triangles in imbedded maps.

Plot Establishment: Forest Health Protection and Idaho Department of Lands (IDL) staff located 12 plots across three sites: St. Joe; Clearwater; Nez Perce (Figure 3). At each site we stratified four plots to include

moderate defoliation-wet site; moderate defoliation-dry site; severe defoliation-wet site; severe defoliation-dry site (Figure 4). Moderate and severe defoliation calls were based off the 2019 draft aerial detection survey data.

The week of Sept 30, 2019, crews established 4 variable radius plots at each site. Plots were located at least 100 meters apart and contained a minimum of 15 "IN" overstory trees. Monitoring plots were established using the hemlock looper monitoring protocol v.2 (Appendix A). From plot center, variable radius measurements were taken using a basal area factor (BAF) of 20 on the primary plot where trees ≥ 5" dbh were measured. If a BAF 20 was not affording enough coverage of stand level composition (at least 15 "IN" ≥5-inch dbh trees), then crews switched to the appropriate BAF.

Mensuration data collected for each "IN" tree included: species, status (live or dead), diameter at breast height (dbh), height, canopy position, defoliation, damage agents (up to three), and life stage of hemlock looper observed. All tree regeneration less than five inches dbh was tallied in a 1/50th acre fixed radius microplot (radius = 16.7 feet) centered at each variable-radius plot. Tree density and basal area measurements may be skewed due to imposing diameter limits (5-inch dbh) on a variable radius plot and adding a fixed radius microplot.

Defoliation classification: The 5-class hemlock looper defoliation system was developed in August 2019 in order to capture consistent insect-caused defoliation measures across the range of the outbreak. The five-class system is based off Wickman's Douglas-fir tussock moth guide on defoliation and predicting tree damage (1974). The hemlock looper system uses thirds with additional classes added to capture no defoliation and severe defoliation (Appendix B).

0 = no defoliation
1 = Light defoliation (1-33%)
2 = Moderate defoliation (34-66%)
3= Heavy defoliation (67-90%)
4=Severe defoliation (>90%)

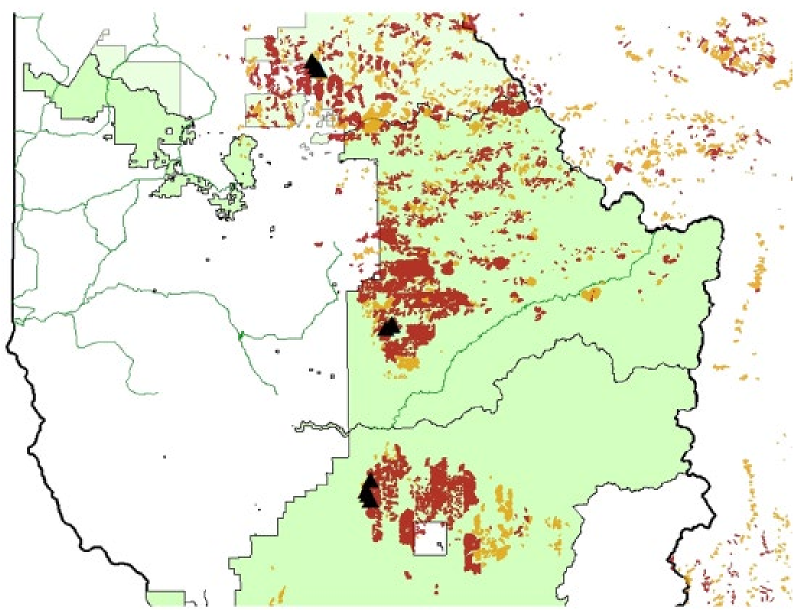

Figure 4. Aerial detection survey data from the 2019 flight season mapped extensive instances of moderate (orange) to heavy (red) defoliation across northern Idaho and western Montana. From north to south, St. Joe, Clearwater, and Nez Perce plots are represented by black triangles.

2019 and 2020 Egg Sampling: Sampling viable eggs is often the best indicator of future defoliation and population pressure projections. Crews installed one white polyurethane (17x30 cm) foam strip on the north facing side of one primary host tree on each plot to capture egg count data (Hébert and Berthiaume 2006, Hébert et. al 2003, Hébert et. al 2004, Shore 1990). When access allowed, entomologists removed foam strips and collected lichen for egg sampling. Nez Perce-Clearwater lichen and foam strip collections occurred June 26, 2020. The St Joe collections were delayed due to road improvements; strips and lichen were collected on September 1, 2020. Clearwater plots had 3 additional polyurethane foam samples. We used the hot water processing methods to extract eggs from lichen (Dickinson 2019, Randall 2010 and Shore 1990). Due to limitations in time and lichen availability, we sampled 15-20 grams of lichen per plot. Eggs were extracted from lichen and processed on August 26, 2020 and September 3, 2020. Total eggs from oviposition strips and lichen were counted, examined and placed in one of three categories – healthy, parasitized, or old/2019 egg.

In cooperation with a forest industry partner, the forest entomology lab at the University of Idaho assessed egg survival and mortality agents. A total of 30 transects were sampled, 10 points per transect. Within a transect, points were situated in roughly a straight line and points were 50 m apart. Eggs populations were sampled by collecting lichen from a 300 cm^2 area on a single tree per point. Samples were collected in November and December of 2019 and maintained outdoors under ambient temperature conditions. When possible, five eggs per point were collected and placed into individual containers with synthetic diet and kept at 25^oC. These eggs were monitored for hatch and parasitoid presence. Larvae were monitored for 21 days after hatching to ascertain the presence and extent of entomopathogenic activity. An additional five eggs per point were separated and monitored for parasitoid emergence. Total eggs per sample were counted. In addition to the eggs, any western hemlock looper pupae that were present in the lichen were placed into individual rearing cups, kept at 25^oC and emerging parasitoids were collected and identified. Stand (density, basal area and proximity to defoliated stands) and tree (species, dominance class and defoliation) characteristics were measured.

Data Analysis

We offer basic summaries (averages and percent of affected sample) and qualitative information from the August 2019 western hemlock looper collections. We summarized life stages, presence/absence of symptoms associated with viral and fungal pathogens, presence/absence of parasitoids, and recorded number of western hemlock looper collected from each sampled host species.

Summaries of plot data included analyzing data collectively and by site. The following were calculated for the western hemlock looper monitoring plots and sites:

1. Total live trees/acre (TA), microplot data and average defoliation level
2. Total live basal area (.09m^2/.40 hectare), overstory plot data and average defoliation level
3. Average defoliation by site
4. Average defoliation by plot
5. Overstory species representation
6. Understory species representation (seedling and sapling representation)
7. Average defoliation by species
8. Average defoliation by diameter classes, overstory data

Results

2019 Live Insect Collections: Life stage data from western hemlock looper collections indicated late instar larvae were most prevalent, during our August 28-29, 2019 sampling period. We also collected western hemlock looper pupae, indicating the beginning of western hemlock looper pupal stage for the Nez Perce populations. High densities of looper pupae were recovered from lichen on lodgepole pine, during the August 28-29, 2019 insect collection effort. We primarily collected western hemlock looper from four different hosts (Douglas-fir, grand fir, lodgepole pine, and subalpine fir). Grand fir had a total of 27 western hemlock loopers collected from it and lodgepole pine had a total of 26 individuals. Both lodgepole (pupae in lichen) and grand fir (larvae) yielded the highest densities during our collection period. One-half cubic meter of lichen moss was collected from lightly defoliated, mature grand fir at two sites along FS road 103, Clearwater NF, on September 24, 2019. A thorough examination of the material yielded only four eggs. This negligible amount was curious, considering the number of adults present in tree foliage and flying about.

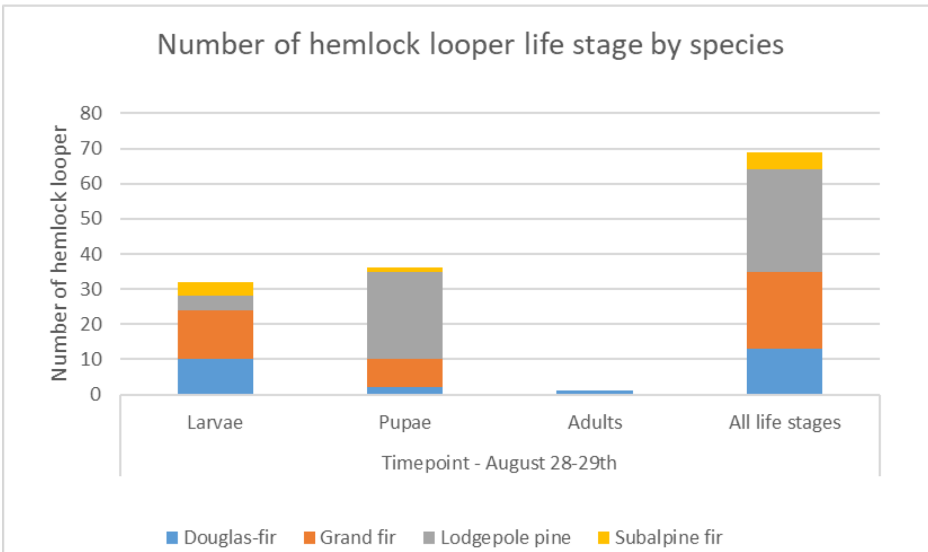

Figure 5. Summary data of live western hemlock looper collections from Nez Perce NF near Elk City, August 28th and 29th.

A small proportion of the live insects collected were healthy and live at the time of laboratory post processing (5-10 days after collection). Larvae symptoms associated with viral and fungal infections were present in our insect collections, including deflated bodies or hardened and hollow integument. A higher proportion of live western hemlock looper collections were dead upon laboratory processing. Of the 81% dead larvae, anywhere from 86-100% of those dead larvae showed symptoms associated with viral or fungal infection.

Collection processing began with 36 pupae, but toward the end of laboratory processing, several additional larvae passed into pupal stage. Approximately six additional pupae were processed in mid-November (November 18, 2019). Two of 42 or 5% of pupae completed full development after collection (adult moths); we assume these insects were healthy and otherwise free of virus, entomopathogenic fungi, and parasitoids. Thirty-six of 42 or 85% pupae did not complete development. We excavated all unalive pupal cases and recovered *Ichnuemonidae* parasitoids from six hemlock looper pupal cases. Four of 42 or 10% of hemlock looper pupae appeared healthy. The other 30 dead pupae appeared to be empty with powdery, dry white and bright green remains at the end of the pupal case. These symptoms suggest that 71% (30 of 42) of hemlock looper pupae were parasitized or otherwise unable to complete development. We suspect time under laboratory conditions and in refrigeration affected the numbers of dead hemlock looper pupae recovered after 10 days of processing live collections.

Collections from Nez Perce-Clearwater NF proposed project areas and surrounding forest indicate parasitoid presence (Figure 6). The highest number of parasitoids (n=6) were recovered from black lichen collected on lodgepole pine. There was light defoliation noted on lodgepole pine. However, it is worth noting that lodgepole pine may not have offered western hemlock looper suitable feeding material through its entire feeding window, but that lodgepole pine had adequate lichen (preferred habitat) available for looper pupation.

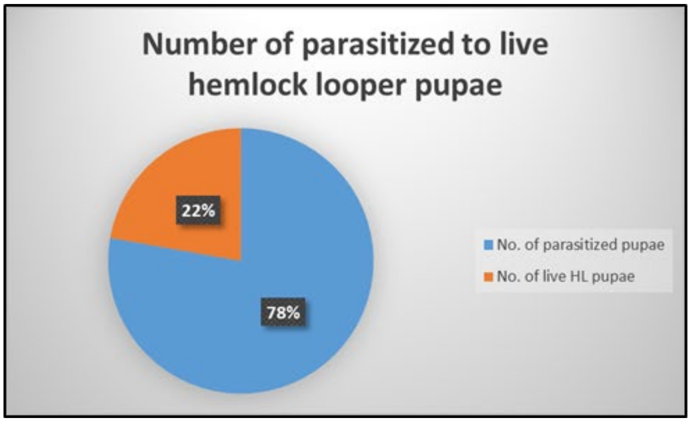

Figure 6. Forest Health Protection hemlock looper collections indicated a high percentage of parasitized western hemlock looper pupae from the August 28-29, 2019 collections (left). Laboratory processing of hemlock looper pupae revealed (*Ichnuemonidae*) parasitoid wasps and pupae symptomatic of parasitism (right).

Western hemlock looper monitoring plots: The hemlock looper monitoring plots and plot location reconnaissance mission indicated that in all cases defoliation severity was overestimated by aerial surveyors (Table 2, stratification v. average defoliation). Given the challenges associated with accurately defining damage agents (see Outbreak History, above), especially when multiple hosts are being defoliated, we found the ADS estimates to be especially helpful and continue to discuss ground data with aerial surveyors in order to inform and assist with their flight missions.

Table 2. Summary table of the variable radius plot locations across all 12 plots and three sites. [1] Forest Health Protection and Idaho Department of Lands stratified the location of monitoring plots based on aerial detection survey calls for defoliation intensity (moderate and severe) and ground-based aspect conditions (wet and dry sites). Defoliation was averaged across all hosts at each site.

Site Name	Plot Number	Location	[1]Stratification (ADS call-Aspect)	Average defoliation level
Clearwater				
	1	N 46.40750 W 115.59511	Moderate-Dry site	1.5
	2	N 46.40702 W 115.59462	Moderate-Wet site	1.3
	3	N 46.40024 W 115.61497	Severe-Dry site	1.8
	4	N 46.40881 W 115.59290	Severe-Wet site	2
Nez Perce				
	1	N 45.97245 W 115.70373	Moderate-Dry site	1.3
	2	N 45.94890 W 115.68723	Moderate-Wet site	1
	3	N 45.99953 W 115.68385	Severe-Dry site	2
	4	N 45.96122 W 115.69577	Severe-Wet site	1.6

St. Joe				
	1	N 47.08402 W 115.86072	Moderate-Dry site	1.9
	2	N 47.08191 W 115.85663	Moderate-Wet site	1
	3	N 47.09223 W 115.87179	Severe-Dry site	2.3
	4	N 47.10696 W 115.88468	Severe-Wet site	2.2

Defoliation was calculated for all measured trees at each plot and averaged by site (Table 3). Instances of moderate, heavy, and severe defoliation were recorded at all three sites. On average, the St. Joe sites experienced the highest defoliation levels (2.1 or moderate defoliation) in 2019. Clearwater plots had light-moderate defoliation on average and the Nez Perce plots averaged light defoliation.

Table 3. Site-level defoliation includes defoliation across ≥ 1-inch dbh sampled trees and saplings averaged for each site[1].

Site Name	Location	Total trees (≥1" dbh)	Defoliation (trees >5" dbh)	Defoliation (trees <5" dbh)	Site-level defoliation[1]
St. Joe	Avery, ID	119	1.9 (light-moderate)	2.4 (moderate)	2.1 (moderate)
Clearwater	Pierce, ID	81	1.6 (light-moderate)	1 (light)	1.6 (light-moderate)
Nez Perce	Kooskia, ID	80	1.4 (light)	1.5 (light)	1.4 (light)

Overstory measurements: A total of 203 overstory trees were measured across 12 western hemlock looper monitoring plots. Overstory tree species included: Douglas-fir, Engelmann spruce, grand fir, mountain hemlock, pacific yew, subalpine fir, and western red cedar. Preliminary monitoring plot summaries indicate that grand fir made up just over 50% of the sampled overstory species (Figure 7). The most prevalent overstory species were grand fir, subalpine fir, Douglas-fir, and Engelmann spruce, respectively.

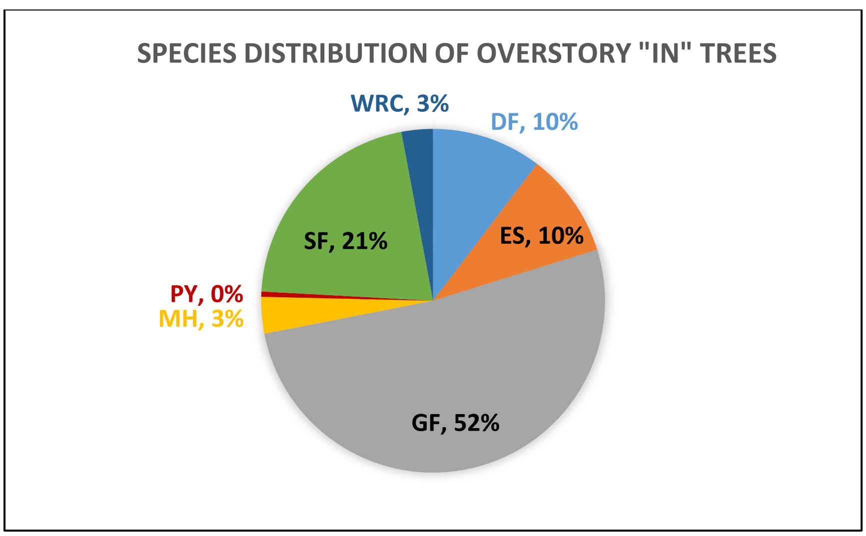

Figure 7. Overall species distribution of overstory (≥5" dbh) trees sampled at three locations across the footprint of the hemlock looper outbreak. Tree species SF= Subalpine fir, GF= grand fir, MH= mountain hemlock, ES= Engelmann spruce, DF= Douglas-fir, PY= Pacific yew, and WRC=western red cedar.

On average, overstory western red cedar and subalpine fir sustained the highest levels of defoliation (Table 4). Light and light-moderate defoliation was common across all other hosts. The St. Joe site was the only location with subalpine fir representation in plots. At the Clearwater site, Douglas-fir and grand fir endured

light-moderate levels of defoliation. All overstory tree defoliation at the Nez Perce site fell between light and light-moderate categories.

Table 4. [1]Species distribution of overstory size class (≥ 5-inch dbh) sampled trees for each site. Average host species defoliation levels are summarized by site and across sites. [2]Total "IN" trees and average species representation summarizes overall distribution across all three sites. [3]Host species defoliation levels are averaged and summarized for all 3 sites. Tree species SF= Subalpine fir, GF= grand fir, MH= mountain hemlock, ES= Engelmann spruce, DF= Douglas-fir, PY= Pacific yew, and WRC=western red cedar.

Site	Species	Total "IN" trees, overstory plot[1]	% of species in overstory (by site)	Avg. Species defoliation (by site)[1]
St. Joe	DF	11	15.5%	0.9
	ES	10	14.1%	0.4
	MH	7	9.9%	1
	SF	43	60.6%	2.6
Nez Perce	ES	1	1.6%	1
	GF	60	96.8%	1.4
	PY	1	1.6%	1
Clearwater	DF	10	14%	1.7
	ES	9	13%	1.1
	GF	45	64%	1.5
	WRC	6	9%	3
TOTAL[2]	DF	21	10.3%	1.3
	ES	20	9.9%	0.83
	GF	105	51.7%	1.45
	MH	7	3.4%	1
	PY	1	0.5%	1
	SF	43	21.2%	2.6
	WRC	6	3.0%	3

The dominant canopy position trees made up the majority of the overstory plot trees measured. Approximately 50% of those dominant trees sampled fell into the "light defoliation" (1) category. Over half of the intermediate position trees had moderate-severe defoliation recorded at installation (Figure 8). There was less overall representation in the >30-inch dbh size class across the plots (Figure 9), but the ratio of light defoliation to moderate-severe decreased noticeably in the intermediate and overtopped canopy positions.

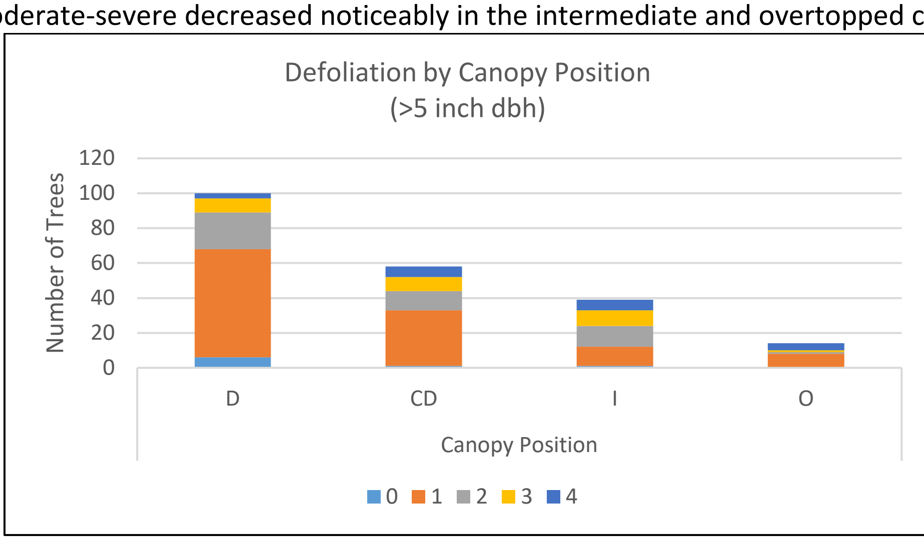

Figure 8. Distribution of western hemlock looper defoliation (0=no defoliation, 1=light, 1-33%, 2=moderate, 34-66%, 3=heavy, 67-89%, and 4=severe, >90%) on trees (>5" dbh) sampled from variable canopy positions (D=dominant, CD=co-dominant, I=intermediate, O=overtopped).

The smallest diameter class (5-9.9-inch dbh) was affected by the highest amount (approximately 10) of severely defoliated trees recorded. As well the 5-9.9 inch and 35-39.9-inch diameter classes had the highest proportion of moderate-severe defoliation. Nearly half of the trees in the 25-29.9-inch diameter class were moderately-severely defoliated. There were no recorded instances of trees >25-inch dbh with no defoliation (0) from western hemlock looper (Figure 9).

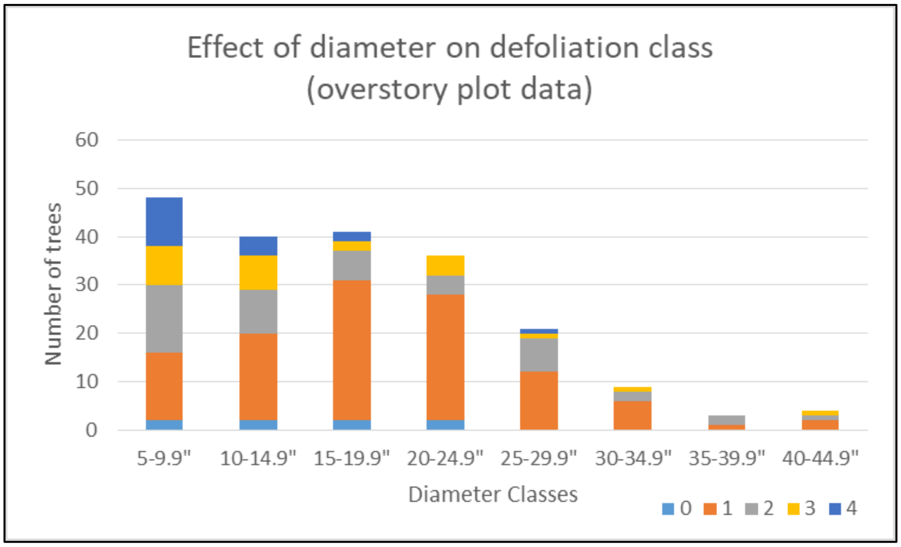

Figure 9. Distribution of western hemlock looper defoliation (0=no defoliation, 1=light, 1-33%, 2=moderate, 34-66%, 3=heavy, 67-89%, and 4=severe, >90%) across the eight diameter classes included in the sampling effort.

Understory measurements: Understory tree species across the 12 monitoring plots included: grand fir, Engelmann spruce, mountain hemlock, subalpine fir, pacific yew, and western white pine. The most prevalent understory sapling sized species sampled include subalpine fir (51%), grand fir (24%), and Engelmann spruce (13%) (Figure 10).

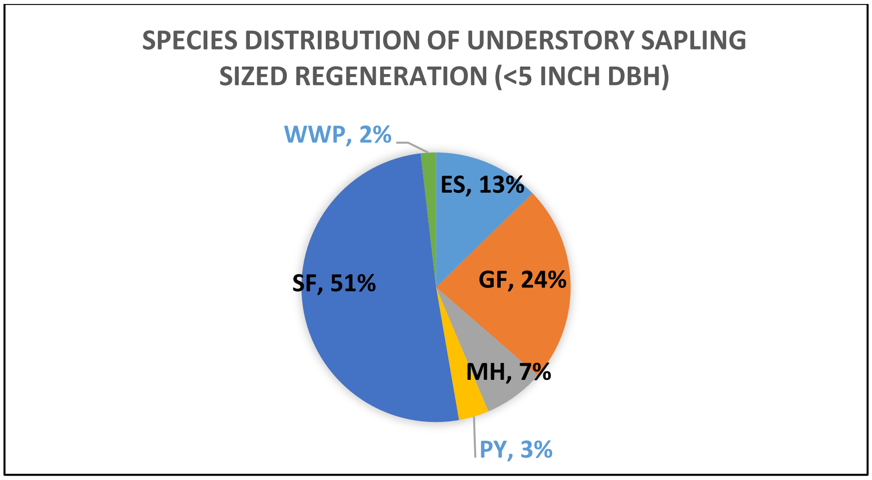

Figure 10. Overall species distribution of understory saplings (>1-4.9" dbh) sampled at three locations across the footprint of the hemlock looper outbreak. Tree species SF= Subalpine fir, GF= grand fir, MH= mountain hemlock, ES= Engelmann spruce, WWP=western white pine, and PY= Pacific yew.

Defoliation impacts on regeneration size class trees ranged from no defoliation to heavy defoliation across the 12 microplots (Table 5). Understory species representation was largely comprised of true fir. Heavy defoliation in regeneration size classes was limited to plot 4 at St. Joe. St. Joe was the only location of the three sites that had subalpine fir represented in the understory. The understory subalpine fir component at St. Joe (and overall) endured the highest levels of defoliation (2.7, moderate- heavy). Engelmann spruce and grand fir experienced the second highest levels (1.5, light-moderate) of defoliation across all understory species sampled. The grand fir sampled on St. Joe microplots had an average defoliation level of 2, or moderate. Nez Perce and Clearwater grand fir average low defoliation levels (1.4 and 4, respectively); this was lower than the overall average for this species and lower than what was captured on the St. Joe.

Table 5. [1]Species distribution and density (trees/acre and % TPA) of regeneration size class (≤ 4.9-inch dbh) sampled trees for each site. Average host species defoliation levels are summarized by site and across sites. [2]Total "IN" trees and average species representation summarizes overall distribution across all three sites. [3]Density and host species defoliation levels are averaged and summarized for all 3 sites. Tree species SF= Subalpine fir, GF= grand fir, MH= mountain hemlock, ES= Engelmann spruce, DF= Douglas-fir, PY= Pacific yew, WH=western hemlock, WP=western white pine, and WRC=western red cedar.

Site	Species	Total "IN" microplot trees[1]	Trees/Acre[1]	Avg. Species defoliation (by site)[1]	Avg. Species representation by site (% TPA)[1]
St. Joe	ES	15	750	1.5	11%
	GF	1	50	2	0.7%
	MH	10	500	0.6	7.7%
	SF	101	5050	2.7	78%
	WH	1	50	1	0.7%
	WL	1	50	1	0.7%
	WP	1	50	0	0.7%
Nez Perce	ES	1	50	1	4.5%
	GF	19	950	1.4	86.4%
	PY	2	100	1	9.5%
Clearwater	GF	9	450	1	75%
	WRC	3	150	1	25%
	Species	**Total "IN" [2]**	**Trees/Acre[3]**	**Avg. Species defoliation[3]**	**Avg. Species representation (% TPA)[2]**
TOTAL[2]	ES	15	750	1.5	9.2%
	GF	29	1450	1.5	17.8%
	MH	10	500	0.6	6.1%
	PY	2	100	1	1.2%
	SF	101	5050	2.7	62%
	WH	1	50	1	0.6%
	WL	1	50	1	0.6%
	WP	1	50	0	0.6%
	WRC	3	150	1	1.8%

Both overstory and understory trees endured the full range of defoliation. Overstory western red cedar suffered higher levels of defoliation (3), on average, than understory western red cedar (1). Understory and overstory subalpine fir had similar levels of defoliation, 2.7 and 2.6 respectively.

The University of Idaho transects were in north-central Idaho. Grand fir (51%) and Douglas-fir (24%) were the most frequently sampled tree species, followed by Engelmann spruce (9%), western redcedar (8%), western hemlock (4%), western larch (2%), subalpine fir (1%) and western white pine (1%). The sample trees were primarily dominant or co-dominant individuals (83%) but intermediate or suppressed trees (17%) were used when necessary.

2019-2020 Plot Egg Sampling: Egg sampling completed by University of Idaho captured the early egg stage. In addition, in 2020, we wanted to capture the full range of parasitoid affects, including those that are known to affect western hemlock looper eggs in the late spring. Egg counts were extremely low at all plots (on average only 12 eggs/plot, Table 6). We also collected lichen from Elk Summit since we had sampled the same area in August 2019 and made live insect collections.

Randall (2010) predictions for western hemlock looper eggs per 100-gram moss sample predictions are as follows: 0-4 viable eggs = no defoliation, 5-26 viable eggs = light defoliation, 27-59 viable eggs = moderate defoliation, and 60+ viable eggs = severe defoliation. Not all lichen collections made in 2020 were 100 grams, therefore classifying egg counts based on Randall's methods is difficult. We have calculated site level defoliation projections to allow our sample sizes to fit current guidance.

Table 6. Egg sampling data from St. Joe, Clearwater and Nez Perce western hemlock looper monitoring plots. Eggs were recovered from a combination of lichen and polyurethane oviposition foam strips deployed in October 2019 at monitoring plots. Elk Summit lichen collections occurred on July 14, 2020, during a functional assistance trip. *Asterisk indicates sites with less than 100 grams total of lichen processed.

Site name	Healthy eggs	Parasitized eggs	Old eggs	2020 Projections
St. Joe	0	2	6	No defoliation*
Clearwater	2	11	8	No defoliation
Nez Perce	0	3	5	No defoliation
Elk Summit	0	0	7	No defoliation*
Total	2	16	26	No defoliation

There was a higher egg recovery from lichen samples than from oviposition strips. A total of 44 hemlock looper eggs were recovered across all twelve plots from both lichen and oviposition strips. Only 5% (2 eggs) were healthy, 36% (16 eggs) were parasitized, and 59% (26 eggs) were last year's eggs. The severe defoliation-dry site plot on the Clearwater yielded the highest egg counts. The severe defoliation-wet site on the St. Joe and the moderate defoliation-dry site yielded the highest egg counts. Percent parasitization from highest to lowest across the three sites was Clearwater (52%), Nez Perce (43%), and St. Joe (25%) respectively. Elk Summit egg recovery was low, and only 61 grams of lichen with 7 old eggs were recovered. Low egg counts, such as what we recovered in June 2020, indicated decreasing population pressure and support projections for no defoliation for 2020.

2020 Live Insect Collections: On July 14, 2020, we returned to Elk Summit for a functional assistance request. Many trees had recovered, however examples of top kill, understory and overstory tree mortality from severe defoliation were noted. We collected live insects using the same methods as the 2019 live insect collections. Live insect collections included 5 early instar, sick western hemlock looper larvae. Our collections also contained >30 early instar Douglas-fir tussock moth larvae from the crown of defoliated and recovering Douglas-fir and grand fir. In order to monitor for additional defoliation from Douglas-fir tussock

moth, we added several Douglas-fir tussock moth traps to the Elk Summit area in 2020. Five traps were deployed in late July and collected at the end of September. We also completed timed egg mass surveys at the St. Joe, Clearwater, and Nez Perce monitoring plot locations. Egg mass survey results indicated no Douglas-fir tussock moth egg mass presence in October 2020. Total Douglas-fir tussock moths trapped in 2020 for Elk Summit was 275.

Conclusion

Our 2019 insect collections suggested that the Nez Perce populations entered late instar larval and pupal life stages in late August. Egg, larvae, and pupae laboratory processing indicated that biotic natural controls (virus, fungus, and pupal parasitoids) were present in the Nez Perce, Elk City western hemlock looper populations. Egg samples collected in 2020, from lichen and overwintered oviposition substrate, suggested a western hemlock looper population decline for 2020, and projected no defoliation for the St. Joe, Clearwater and Nez Perce locations.

Preliminary results from egg and larvae rearing at University of Idaho indicated that a viral pathogen was present in the overall population. Data will be analyzed to determine the relationship between viral infection and tree or stand parameters. Pupal parasitoids are continuing to emerge. At this point, species identifications have not been confirmed but, both ichneumonids (92%) and chalcids (8%) have emerged from pupae.

In 2019, the highest levels of western hemlock looper defoliation occurred in overstory western red cedar, subalpine fir (all size classes) at the St. Joe site, and host trees in the intermediate and overtopped canopy positions. The 5-14.9 inch and 25-29.9-inch diameter classes endured the most defoliation. Insect biology, host preference and stand dynamics (host shade tolerance) were factors in monitoring results. Monitoring results indicated that western hemlock looper larval feeding did not cause immediate tree mortality in 2019. In fact, most of the defoliation measurements were in the light-moderate category. Light-moderate categories of defoliation rarely result in defoliator-induced tree mortality (Wickman 1974). By 2020, active defoliation was recorded as either light or no active defoliation, and most trees had recovered. Preliminary results from the October 2020 plot remeasures indicated only 3 severely defoliated overstory trees (1 grand fir and 2 subalpine fir) were killed during the western hemlock looper outbreak. Understory trees were impacted by defoliation more so, with approximately 15 trees <5” dbh recorded as dead from severe western hemlock looper defoliation. These monitoring plots are only a small sample of the overall 425,000-acre event. Subsequent measurements aim to capture future (post-outbreak) tree mortality, presence of other damage agents, and cumulative defoliation impacts across all sampled trees.

Outside of western hemlock looper defoliation, compounding forest health factors deserve consideration, such as the role of root disease, balsam woolly adelgid (*Adelges piceae*), subalpine fir decline, weather, climate, and the synergistic effects of bark beetles, drought and defoliators. Under drought conditions, the potential for bark beetles attacking already weakened and defoliated trees increases (Ferrell et al. 1993 and Berryman, Ferrell 1988, Kolb et al. 2016). Spruce beetle activity and recent wildfire activity on the Nez Perce-Clearwater National Forests have contributed to high amounts of standing dead overstory Engelmann spruce (Nez Perce site), leaving few live Engelmann spruce seed sources on site. In several cases, hemlock looper defoliation of regeneration size class Engelmann spruce was recorded as heavy-severe. In addition, forest health specialists and land managers have observed decline of western red cedar throughout northern Idaho, eastern Washington, and western Montana (Fischer, personal communication and Cleaver and Pederson 2017). In spring 2017, Nez Perce-Clearwater National Forests land managers noted widespread decline and mortality of western red cedar along the Selway River corridor (Cleaver and Pederson 2017). The full extent of western red cedar decline is unknown but has been reported across the species’ range (WA, OR, ID, Canada) by several agencies. The impact of ongoing western red cedar decline with the added stress of

western hemlock looper defoliation remains unknown. Growing Douglas-fir tussock moth numbers indicates potential for additional defoliation at the Elk Summit site in 2021.

These monitoring observations provide information on the status of western hemlock looper populations, defoliation intensity and tree health at three northern Idaho sites. Final western hemlock looper plot data analyses will be used to inform future tree mortality projections, guide biologically appropriate management recommendations, and inform managers of sustained damage levels across all host species. Natural control presence, the 2018-2019 increase of defoliated acres, 2019 defoliation footprint, and egg sampling forecasted declining populations. The 2020 defoliation projections indicated no new western hemlock looper-caused defoliation. This was largely supported by the 2020 live insect collections and the October 2020 plot remeasure data and ground-based observations.

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Appendix A. Western hemlock looper monitoring protocol.

PROTOCOL FOR MONITORING PLOTS FOR HEMLOCK LOOPER
Version 2.0 February 2020

Plot Establishment
We have defined 3 site areas: St. Joe; Clearwater; Nez Perce to collect monitoring data on hemlock looper defoliation. Establish 4 total plots at each site area. Plots should be at least 100 meters apart. Plots should contain at least 15 "IN" trees in variable radius primary plot measurements. Record the latitude and longitude in decimal degrees (WGS84) for each plot center. Plot centers should be marked with an orange/red stake. From plot center, variable radius measurements will be taken using a basal area factor (BAF) of 20 on the Primary Plot where trees ≥ 5" dbh will be measured. If a BAF 20 is not affording enough coverage of stand level composition, then switch to appropriate BAF to capture at least 15 "IN" trees. Nested microplot to measure all tree variables for saplings ≥1"dbh but less than 5" dbh on 1/50 acre (16.7 feet radius) fixed radius plot, where plot center is also plot center for the nested microplot. Tree species and % defoliation to be recorded for seedlings >1' height and <1" dbh on the microplot. At dbh, nail a numbered aluminum tag facing toward plot center to each measured live tree >1" dbh. From plot center, go north and mark the first tree. Starting with the primary plot trees, number trees consecutively proceeding east around plot center.
Install one foam strip at on a primary host tree on each plot to capture egg count data. Record location (tree tag number) of foam strip for later collections. Staple top, narrow end of a 17x30 cm strip of white polyurethane foam to north side of tree at dbh. Attach foam so that it is arched, and not flat against bole. This provides easy access for oviposition on the unerside. (Hebert et al 2003 suggest 10-40 foam strips/site)

Site level data
TimePoint (Install plots in 2019, 2019= install time point, re-measure annually for three years after last year defoliation is observed)
Date (day, month, year of measurements)
Crew (First initial and last name of all crew members)
Area (Full descriptive name of location: St. Joe; Clearwater; Nez Perce; moderate or heavy defoliation; dry or wet aspect)
Basal Area Factor (BAF) (Record basal area factor used at each plot)
ADS Class (Record the defoliation call made by surveyors during current year aerial detection survey flight, this can be completed in office later; classes will be 50-75% or >75% defoliation)
Ownership (USFS, State, Private, other)
Plot level notes (Notes about site conditions, any additional damage generally affecting the plot such as harvest, animal, root disease or other damage and general severity of damage, if applicable.)
Helpful to record plot directions: On the back of the field form provide written directions to the plot from the nearest identifiable Forest map location. Include road numbers, north arrow, distances between landmarks. These plots will be remeasured in future years. Write directions for someone who has never seen the area before. To be completed in the office, include google earth image with plot center and main access roads.

Primary plot level data
Plot (Each site will have four plots representing a combination of moderate or severe defoliation and wet or dry aspect. Plot should be identified as M-D = moderately defoliated stand on a wet aspect, M-W = moderate wet, S-D = severe dry, S-W = severe wet.
Lat (Decimal degree WGS 84) *Note that GPS in phones and tablets have low accuracy. Collect coordinates with at least a recreation grade GPS unit

Long (Decimal degree WGS 84)
GPS error (record to nearest foot, this may help in locating plots)
Elevation (Feet)
Aspect (Direction at plot center that water would travel downhill, recorded to the nearest degree, enter NA if flat)
Slope (Record to nearest whole number as averaged from uphill and downhill slope)

Tree level data
TagNo (Tree Number included on each tag nailed to the live tree at plot installation)
TreeSpecies (Tree species SF= Subalpine fir, GF= grand fir, MH= mountain hemlock, LP= lodgepole pine, ES= Engelmann spruce, WBP= whitebark pine, WP=western white pine, PP= ponderosa pine, DF= Douglas-fir, WRC=western red cedar, WH= western hemlock, L=larch, ASP=aspen, CW=cottonwood, PB=paper birch)
Status (Tree live =1 or dead =0 based on tree external appearance. If uncertain scratch into bark at dbh or break branch to confirm live phloem. This measurement will be repeated in consecutive years.)
DBH (Diameter at breast height (4.5' on uphill side of tree) measured to tenths of inch for all trees at or >1" dbh, round down to nearest tenth. Measured year of install only.)
Height (Measured to foot when plots installed, measured year of install only.)
Canopy Position (Can Pos) (For live "IN" trees and those measured in the microplot estimate canopy position as open grown (OG); dominant (D); codominant (CD); intermediate (IN); overtopped (OT)
Top kill (This measurement is taken the second year of the defoliation event (Wickman 1978). Top kill will be recorded in 2020 and every year thereafter through the end of survey. This measurement is recorded in categories based on total feet of top kill. Categories: **0** (no top kill); **1** (1-5 ft); **2** (5-10 ft); **3** (10-15 ft); **4** (15-20 ft); **5** (>20 ft).)
% Defoliation (This measurement will be made in fall to ensure we have included any impacts to new growth in current defoliation estimates. Defoliation will be measured roughly in thirds with additional classes added for no defoliation and severe defoliation. Examine all of the foliage that is visible from the ground. Focus attention to inner portions of limbs where needles may still be green or only lightly impacted as well as outer portions of limbs where impacts may appear more severe. Divide crown into thirds, then visually move intact needles down the crown to fill in defoliated sections of the crown and record visualized estimate of total crown with defoliation. Visualization exercise includes all needles, current and older growth. Defoliation classes: 0% or no defoliation = **0**; 1-33% of crown impacted or Light defoliation=**1**; 34-66% of crown impacted or Moderate defoliation = **2**; 67-90% of crown impacted or Heavy defoliation=**3**; >90% defoliation (Severe=**4**). This measurement will be repeated in consecutive years.
Picture (yes or no that a picture of the tree taken from plot center and from another angle, if needed to best visualize defoliation. Take at least four pictures/plot. Take a picture of at least one tree in each defoliation category recorded for that plot. Name downloaded pictures with area plot tree and year, i.e.; StJoe_SD_12_2019)
Damage agent 1 (This is a broad category meant to record other damage agents impacting the "IN" tree being measured as well as those trees in the nested microplot. Damage agent 1 is defined as those causing the most significant damage. Categories include: bark beetles, defoliation, wood borers, root disease, mistletoe, stem decay, BWA, abiotic, other)
Damage agent 2 (This is a broad category meant to record other damage agents impacting the "IN" tree being measured as well as those trees in the nested microplot. Damage agent 2 is defined as those causing some damage outside of defoliation from hemlock looper. Categories include: bark beetles, wood borers, root disease, mistletoe, stem decay, BWA, abiotic, other)
Damage agent 3 (This is a broad category meant to record other damage agents impacting the "IN" tree being measured as well as those trees in the nested microplot. Damage agent 3 is defined as those causing some damage outside of defoliation from hemlock looper. Categories include: bark beetles, defoliation, wood borers, root disease, mistletoe, stem decay, BWA, abiotic, other.)

Life stage (Record life stages visible for hemlock looper on the tree being measured. E=eggs; L=larvae; P=pupae; A=adults)
Cause of death (This measurement will be taken at the time in which previous "Live" (1) "IN" trees are recorded as newly "Dead" (2). Causes of death include (but are not limited to): hemlock looper defoliation, bark beetle, wood borer, root disease, stem decay/breakage, BWA, or a combination.)

Nested microplot
For saplings between 1" and 4.9" dbh record the same measurements as the primary plots: Tree species (use the same codes as TreeSpecies in primary plots) DBH, Height, Canopy Position, Top kill (in 2020-end of survey), % Defoliation, Damage Agent 1, Damage Agent 2, Life stage, and Cause of death.
For seedlings >1' height and <1" dbh record: Tree species and % Defoliation
Hemlock Looper defoliation 5 class system 0 = no defoliation 1 = Light defoliation (1-33%) 2 = Moderate defoliation (34-66%) 3= Heavy defoliation (67-94%) 4=Severe defoliation (>95%)

Appendix B. Western hemlock looper defoliation class.

Hemlock Looper 5 Class Defoliation Rating System

0 = No defoliation detected; no signs of hemlock looper feeding in foliage (Image of healthy crown tree)

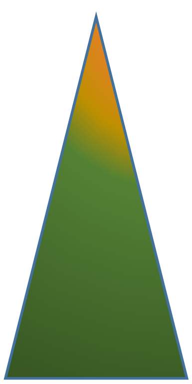
1 = Light defoliation; approximately 1-33% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation

2 = Moderate defoliation; approximately 34-66% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation

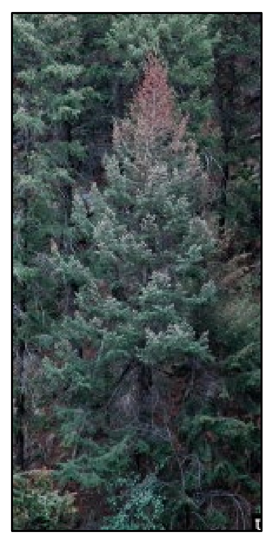
3 = Heavy defoliation; approximately 67-90% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation

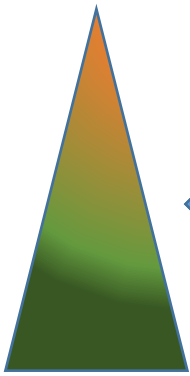
4 = Severe defoliation; approximately >90% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation

0 = No defoliation detected
0% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation
(Photo credit: Forestry images)

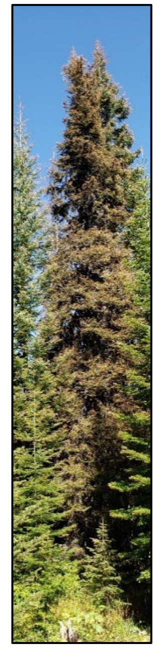


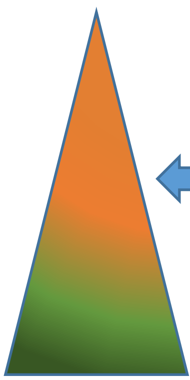
1 = Light defoliation
1-33% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation
(Photo credit: William Ciesla, Forestry images)



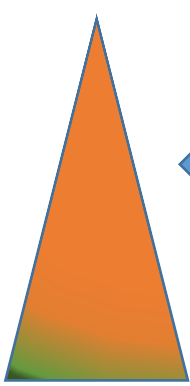


2 = Moderate defoliation
34-66% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation





3 = Heavy defoliation
67-90% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation



4 = Severe defoliation
>90% of foliage is missing, fading or otherwise symptomatic of hemlock looper defoliation